Bidirectional Relationships between Hues and Impressions

Keizo Shinomori[1,2]

shinomori.keizo@kochi-tech.ac.jp
[1]School of Information, Kochi University of Technology, Kami-city, Kochi 782-8502, Japan
[2]Vision and Affective Science Integrated Laboratory, Research Institute, Kochi University of Technology, Kami-city, Kochi 782-8502, Japan

Keywords: Color Impression, Color Appearance, Bidirectional Relationship, Semantic Differential Method, Paired Comparison

ABSTRACT

We measured hue impressions by semantic-words and word impressions by hues and obtained their bidirectional relationship. By this method, we found that color vision normal observers used color appearance to evaluate the hue impressions but color vision deficient observers used their experience associated with color names rather than the appearance.

1 Introduction

Impressions of colors have been measured mostly for two purposes. First, direct impressions of colors are measured to evaluate the property of colors using paired semantic words like bright-dim, light-dark, reddish-greenish and saturated-desaturated. Second, abstract impressions of colors are measured to estimate total impressions of a product using sematic words like active-inactive, beautiful-ugly and superior-Inferior.

A semantic differential (SD) method has been used to measure color impressions in which a subject estimates magnitudes (for example, -3~0~3) for a set of paired words. However, the measurement by the SD method theoretically cannot show a complex relationship between hues and impressions since it has only one directional data set from semantic words to color impression.

Thus, I and my colleagues first investigated the possibility of whether impressions of semantic words showing complex concepts could be stably expressed by hues [1]. We used a paired comparison method and asked subjects to select from a pair of hues the one that more suitably matched a semantic word impression. The results suggested that semantic word impression can be expressed reasonably well by color, and that hues are treated as impressions from the hue circle, not from color categories [1]. By this newly invented method, an additional data set could be obtained in the other direction from color impressions to semantic words. Comparison with the other data set of color impressions measured by the SD method indicated bidirectional relationships between colors (hues) and impressions[1].

In addition, it was expected that this approach would help to investigate the unsolved question of how a color vision deficient (CVD) observer treats the relationship between their color appearance and associated meanings of colors; in Red-Green color-deficient observers such as protan- and deutan-observers, although it is expected that reddish colors do not have strong colorfulness, the Red-Green color deficient observers treat vivid (bright and saturated) Red as a “vigorous” color [2].

2 Experiment

The bidirectional relationships between hues and impressions were measured by two experiments using the paired comparison method (Experiment 1) and the semantic differential method (Experiment 2) [2].

2.1 Exp. 1 (Evaluation of Word Impression by Hue)

Exp. 1 was evaluation of word impression by hue by a paired comparison method. Impressions of nine semantic words expressing abstract meanings (like “tranquil”) were evaluated by 12 hues and White, Gray, and Black in the paired comparison method [2].

We selected eight semantic words in abstract meaning [1]: GENKI-NA (Vigorous), NODOKA-NA (Tranquil), JYUUKOU-NA (Massive), KAGEKI-NA (Extreme), SEIREN-NA (Clean), SABIRETA (Deserted), [SENSAI-NA] (Fine), and SOUREI-NA (Magnificent). We confirmed that these eight words were independent each other in the three core scales [Activity (active-inactive), Potency (superior-inferior), and Evaluation (beautiful-ugly)] in the SD method [1]. MEDATSU (Visible) was added because visibility of color is one of the important topics in color research for applications.

In the Exp. 1, a gray background [Gray] was first presented to each subject for 5 min. After the background adaptation period, one semantic word for evaluation was presented until the subject agreed to start the trials. In main trials, two color rectangles were presented simultaneously side by side in pseudo-random order for all 210 permutations successively (a position of one color at left or right was considered). The observer was asked to select the one color in each pair of colors that was closer to the word impression by pressing a button. A set of 210 trials took about 13 to 16 min (from 3.7 to 4.6 s per trial), and all nine words were measured in random order in one session. Three sessions were conducted for each word for each observer; one color combination under one word was tested in six trials. Thus, each color in a pair with the other color would show from zero to six wins (or six to zero lost) as the result of the comparison.

2.2 Exp. 2 (Evaluation of Color Impression)

Exp. 2 was evaluation of color impression. Color impressions were estimated using a set of 35 paired words by the SD method [2].

In the experiment by the SD method, we added 26 semantic word pairs to these nine words. The positive items in the word pairs in English were Soft, Warm, Beautiful, Delicate, Deep, Fresh, Sweet, Strong, Bright, Grand, Full, Exciting, Hard, Smooth, Thick, Salty, Vivid, Erotic, Cloudy, Clear, Sharp, Permanent, Comfortable, Watery, Light and Thin.

In the Exp. 2, after the 5 min background adaptation period, one color rectangle was presented, and the subject evaluated the color by writing a "✓" mark on a line scale having seven crosses (denoting −3, −2, −1, 0, 1, 2, 3, although the numbers were not shown) for each paired semantic word. It took 6 to 9 min to assess all 35 word pairs for one color. All 12 colors and three additional colors (White, Black, and Gray) were evaluated in one session in pseudo-random order, and three sessions were performed in different days for one observer.

2.3 Apparatus and Calibration

Color stimuli were presented on a 19-inch (48.3 cm) CRT monitor (CPD-G220, Sony Inc.) and on a 27-inch (68.6 cm) LCD monitor (ColorEdge CS2730, EIZO Inc.); the monitors were placed in dark rooms with no illumination.

Chromaticity coordinates and luminance of all colors in the stimuli were measured by colorimeters (CS-200, CS-150, Konica-Minolta Inc.) and a spectral radiometer (CS-1000, Konica-Minolta Inc.).

2.4 Color Stimulus

One color rectangle was 7.0 deg (width) × 6.4 deg (height) in visual angle, edged with black lines of 10 min in width. Twelve stimulus colors were selected from vivid tone (24 color chips) in the Practical Color Co-ordinate System (PCCS) by Japan (Nihon) Color Research Institute: v2(R) [=Red], v4(rO) [=reddish-Orange], v6(yO) [=yellowish-Orange], v8(Y) [=Yellow], v10(YG) [=Yellow-Green], v12(G) [=Green], v14(BG) [=Blue-Green], v16(gB) [=greenish-Blue], v18(B) [=Blue], v20(V) [=Violet], v22(P) [=Purple], and v24(RP) [=Red-Purple]. In one tone of the PCCS, both lightness and saturation are simultaneously and systematically changed in different hues to make one impression. Three neutral colors were added to 12 hues: White(Luminance=77.4 cd/m^2), Gray(12.7 cd/m^2) and Black. which were the same as D65 on the white standard plate, background gray, and the black of the border line, respectively.

2.5 Subjects

Nine color vision normal (CVN) observers (6 female and 3 male) of age 20 to 24 (mean: 22.3) and ten color vision deficient (CVD) observers (one protanope, six deuteranopes, one protanomalous observer, and two deuteranomalous observers; all male) of age 19 to 22 years old (mean: 21.2) participated in the experiments.

The Neitz OT II anomaloscope (LED lamp model, Neitz co. Ltd.) was used to classify color-deficient observers. All observers were naïve regarding colorimetry and the purpose of each experiment; no author was included. The procedures and experiments described in this study conform to the principles expressed in the Declaration of Helsinki and were approved by the Kochi University of Technology Research Ethics Committee.

2.6 Analysis

The data of Exp. 1 for any one word are initially shown as the number of wins in the paired comparison for each hue. The number of wins was modified before calculating the selection rate: 6 wins (all wins) was modified to 5.5 wins and 0 wins (no wins) was modified to 0.5 wins. A (modified) selection rate was set by dividing the number by 6 and by subtracting 0.5 (the guaranteed average of all selection rates). Thus, the selection rate for all wins, 3 wins-3 losses, and the no-wins data becomes 0.417, 0, and −0.417, respectively. This operation is basically equivalent to calculating Z-score under the assumption of normal distribution in which the standard deviation equals to one. In Exp. 2 data, the individual grading points were averaged in one observer group for each semantic word to the 15 colors .

One data set was analyzed separately by principal component analysis (PCA), in which the number of PCs (dimensions) reaches minimum and the direction of the first PC maximizes the variance of the data to account for the data distribution. In comparison between CVN and CVD observers, we combined the data of five CVN observers and five deuteranopes to make a balance of an observer number between observer groups and this one data set was analyzed together using PCA because of high concordance.

3 Results

3.1 Results of Exp. 1

Fig.1 shows the modified selection rate (Z-score) data of two semantic words in CVN observers as a function of stimulus color in the order of hue (circle). Mode fits to the data (denoted by blue curves) were calculated by a linear summation of loading values for first and second principal components (PCs) presented in Fig. 2 (in CVN data) with optimized coefficients .

It is interesting that the selection rates changed gradually in continuous hue for all semantic words. The hues with the maximum and minimum selection rates for one semantic word are almost complementary; it was unexpected before our research [1], CVN observers evaluated semantic word impressions on a scale of complementary-paired colors (hues) corresponding to the maximum and minimum selection rates. These indicate that assignment of hue to semantic words does not depend on the individual impression of a single hue, but rather on the set of neighboring hues in the hue circle; in other words, semantic word impression can be expressed reasonably well by hues, and these hues are treated as impressions from the hue circle, not from color categories.

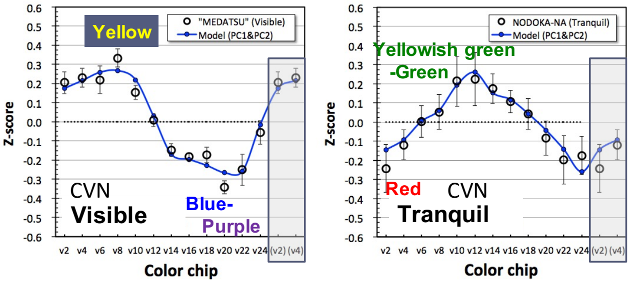

Fig. 1 Selection rate of two semantic words (circles) and model fits (blue curves)

3.2 PCA to the data of Exp. 1

PCA was separately performed to the data of CVN and CVD observers. Cumulative proportions of variance in the first two PCs were 78.2% and 71.5% in CVN and CVD data, respectively. It suggests that the evaluation of word impressions by hues can be described in two dimensions. Loading values for the first and second PCs for each stimulus colors indicate the contribution of colors to the evaluation of all words through the PCs.

Fig. 2 shows the loading values of the first and second PCs for each color in the CVN and CVD data sets. The black ellipse is the best fit to all data points. The interesting result in the distribution of colors as loadings is that the distribution in CVD data is not compressed to one dimensional positions but it is keeping the hue circle shape and is similar to the distribution of CVN data, although it is expected that the color appearance of CVD observers does not have redness and greenness. The four bluish hues (Blue-Green to Violet) tended toward convergence in both observer groups. The other interesting result in the distribution of stimulus colors as loadings is the positions of the white, gray, and black stimuli; these neutral colors can also be fitted by an ellipse. It may suggest that these neutral colors may be treated as colors in a "special" hue circle.

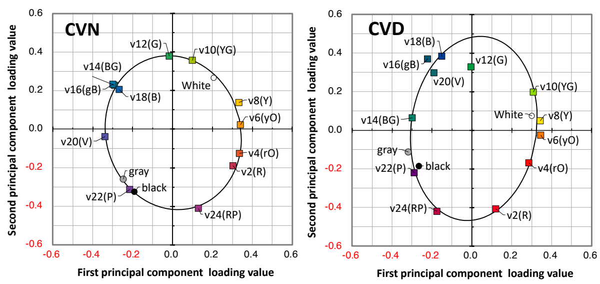

Fig. 2 Distribution of colors defined by the 1st and 2nd PC loading values in CVN and CVD data

3.3 PCA to the combined data of Exp. 1

Since the distributions of colors between observer group was similar, we analyzed the data of five CVNs and five deuteranopes together in PCA. Fig. 3 shows the loading values of the first and second PCs for each color (top panel) and distribution of semantic words obtained by the first and second PC score values (bottom panel) in CVN and deutan observers. The color distribution is approximately in the middle of the two distributions of the CVNs and CVDs shown in Fig. 2. The word distribution was largely different between observer groups; the points of five word scores were approximately on one line, reflecting that the colors used in the paired comparison were treated in one-dimensional scaling (which correlates to lightness; denoted by a green line in top panel of Fig.3) in the deutan observers.

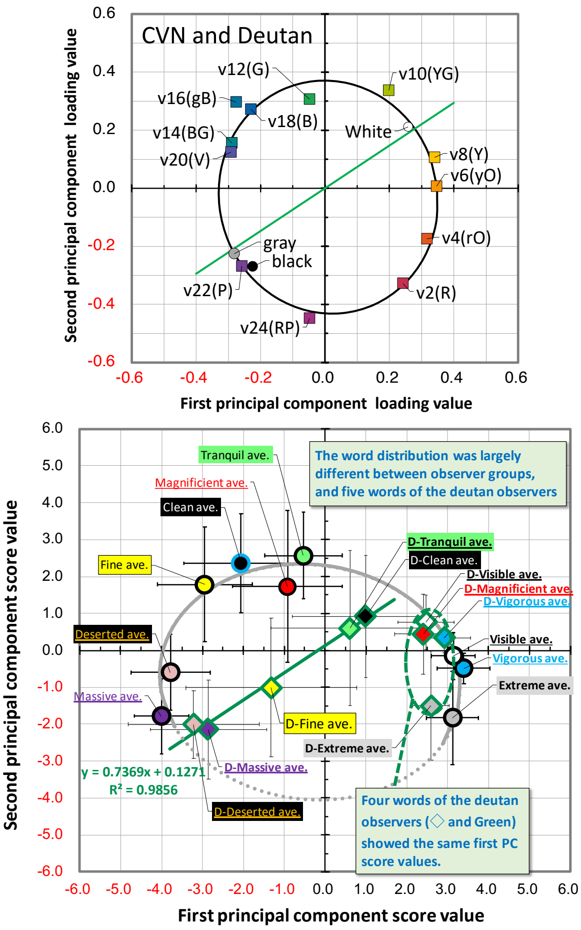

Fig. 3 Loading values and distribution of semantic words obtained by the 1st and 2nd PC score values in CVN and deutan observers.

3.4 PCA to the combined data of Exp. 2

The distributions of words by the first and second PC loading values between observer groups were almost the same. It is not surprising since the usage of semantic words as expressed by loading values of PCs must be the same between observer groups because these semantic words have abstract meanings. Thus, we shows the analysis to the combined data (five CVN and five dutan observers). Fig. 4 shows the loading values of the first and second PCs for each word (top panel) and distribution of 15 colors obtained by the first and second PC score values (bottom panel) in CVN and deutan observers.

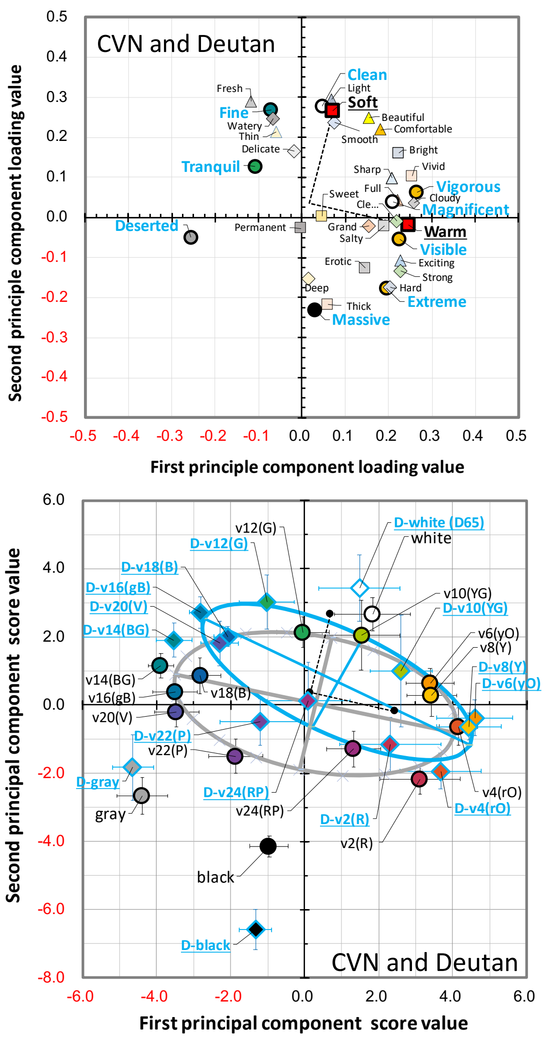

Fig. 4 Distribution of words defined by the 1st and 2nd PC loading values and distribution of colors obtained by the 1st and 2nd PC score values in CVN and deutan observers.

The distribution of hues maintains the structure of the hue circle, although some points are not on the ellipse: Blue-Green (v14), Purple (v22), and Red-Purple (v24) in hues and Black, Gray and White in the neutral colors. The axes directions of the fit ellipse to the CVN data are almost the same as the directions of Warm and Soft defined by the loading values. The results of the SD method using one set of loading values confirmed that the hues are still treated in the hue circle and not compressed to one-dimensional scaling even in deutan observers.

4 Discussion

In the Exp. 1, the selection rates of hues for evaluation of semantic words changed gradually under continuous hue. This supports that assignment of hue to semantic words is not the simple assignment of a color name obtained from color categories and the word impression was expressed by a set of hues in the order of the hue circle. The fact that the colors used in this study were in the same hue circle with the same tone (impression of both saturation and lightness), all differences among these colors can be expressed by two-dimensional variables (two PCs). However, for the deuteranopes who have no detection of Red-Green opponent colors, the selection of hues for the evaluation of semantic words becomes different from those of the CVN observers. The results indicated that except words showing higher score values in the first PC (Extreme, Vigorous, Visible, and Magnificent), five semantic words in this study were evaluated in one-dimensional scaling, which has high correlation to lightness (or brightness). The logic to explain this difference between semantic words (i.e. hierarchization) has not been cleared yet.

The score results of Exp.2 indicate that Black, Gray, and White do not exist on the ellipses reflecting the hue circle. The placement of Black, Gray, and White outside of the ellipse is an intuitively reasonable result, because these neutral colors have special lightness, which can be much higher than, much lower than, or exactly the same as the background, and some effect of lightness difference caused a stronger impression than colors in the hue circle.

5 Conclusion

The results of two different experiments [word impression evaluation by colors (Exp. 1) and color evaluation by words (Exp. 2)] suggest that the CVD observers can understand the hue circle concept in color names but it is not corresponding to the color appearance of the CVDs. In the SD method (Exp. 2), the colors can be recognized by their color names in this experimental condition; however, in the paired comparison method (Exp. 1), the selection of colors in the pair depends on their color appearance. This bidirectional relationship helps the CVDs to keep their performance similar to that of CVNs when the limited number of colors and color names help to create the conceptual hue circle. However, the CVDs tend not to select a variety of colors to express semantic meanings.

References

[1] K. Shinomori, and H. Komatsu, “Semantic word impressions expressed by hue,” J. Opt. Soc. Am., A, Vol. 35, No. 4, pp.B55-B65 (2018).

[2] K. Shinomori, H. Komatsu, and I. Negishi, “Bi-directional relationships between semantic words and hues in color vision normal and deuteranopic observers,” J. Opt. Soc. Am., A, Vol. 37, No. 4, pp.A181-A201 (2020).